Tel: (+ 353-21) 4902468
Fax: (+ 353-21) 4276949
e-mail: physics@ucc.ie

ROINN NA FISICE
Department of Physics

Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Head of Department:
Professor J.G. McInerney

Scientific Workshop on

Ultrafast Nonlinear Optics and Semiconductor Lasers

Co-Chairs: J.G. McInerney and J.V. Moloney

Department of Physics

University College Cork, Ireland

5-8 September 2001

ADVANCE PROGRAMME AND COMPENDIUM OF ABSTRACTS

Please address inquiries to:

Professor John McInerney
Department of Physics
National University of Ireland
University College Cork, Ireland
Tel. (+353-21) 4902327
Fax (+353-21) 4276949
E-mail: mcinerney@ucc.ie

or

Professor Jerry Moloney
Department of Mathematics
University of Arizona
Tucson, AZ 85721, USA
Tel (+1-602) 621-6755
Fax (+1-602) 621-1510
E-mail: jml@acms.arizona.edu

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14. ABSTRACT

The Final Proceedings for Ultrafast Nonlinear Optics and Semiconductor Lasers, 5 September 2001 - 8 September 2001

This is an interdisciplinary conference. Topics include.techniques for the generation of ultrashort pulses, propagation phenomena, interactoin of ultrashort pulses with matter, formation of 'optical strings,' application of ultrashort pulses to remote sensing, and optical pulses with durations comparable to a few optical cycles.

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INTERNATIONAL WORKSHOP IN ULTRAFAST NONLINEAR OPTICS AND SEMICONDUCTOR LASERS AT UCC, 4-8 Sept 2001

ACTIVITY REPORT AND SUMMARY

A high level international scientific workshop in Ultrafast Nonlinear Optics and Semiconductor Lasers was held from 4-8 Sept 2001 under the auspices of the Institute for Nonlinear Science (INS), Department of Physics, National University of Ireland, University College Cork (UCC). It included some 50 senior scientists and advanced students from Europe, North America and Asia. Following registration and a welcoming reception on the evening of Tuesday 4 Sept, the technical programme began on the following morning 5 Sept at 9 am with a keynote address by Dr Nicolaas Bloembergen, of the University of Arizona, who is a Nobel laureate for his pioneering work on nonlinear optics. The full technical programme is given as an Annex to this report.

The workshop was preceded by a 5-day summer school on semiconductor lasers, also sponsored by INS, which was attended by over 30 researchers and research students from all over the world. The lecturers were drawn from UCC, the University of Arizona (USA), Sandia National Laboratories (New Mexico, USA), the University of Marburg (Germany) and the University of Wales, Cardiff, with guest lectures by speakers from the photonics industry.

Nonlinear optics, photonics and emerging technologies

Photonics is the branch of physics in which information and energy are transported by photons (light particles) in the same way as they are by electrons in electronics. It has recently emerged as a key component of information and communications technology, for example in the optical networks which underpin the Internet and World Wide Web. It also holds enormous promise for creating revolutions in illumination, entertainment, medicine, manufacturing, transportation and many other areas of current human endeavour. It is even conceivable, given the high efficiencies (>50%) now attainable using recent generations of compact and rugged high power semiconductor lasers, that remote power generation and transmission could be carried out in outer space and transmitted to terrestrial grids by laser beams. The key scientific problems in all these areas consists of generating, modulating, switching and guiding light at high intensities, and this is the domain of nonlinear optics. Our workshop is one of a series held at UCC since 1994: they are intended to take advantage of Ireland's strategic location as the gateway between Europe and North America, with strong connections in either direction, to invite a select group of scientists, engineers, mathematicians and advanced students across a broad spectrum from basic research to cutting-edge industry. The 2001 workshop concentrated on two distinct but converging areas: dynamics of semiconductor lasers, and ultrashort, highly intense optical pulses.

Ultrashort pulse generation and propagation

Coverage of this area consisted of lectures and discussions on pulse generation, measurement, shaping, supercontinuum generation, and atmospheric propagation. The shortest pulses generated to date are 1.8 fs but it is believed that sub-femtosecond pulses should be achieved

within five years. The standard slowly varying envelope approximation (SVEA) is not valid in these regimes and there are new theoretical challenges to be faced in describing and analysing pulses of the order of a single optical cycle. Extreme UV/soft X-ray pulses generated as high harmonics of visible pulses are promising, careful control and perhaps coherent control of the optical phase is essential, novel experimental diagnostics including Frequency-Resolved Optical Gating (FROG) and its latest extension dubbed GRENOUILLE in a feat of acronymic engineering due to its inventor Dr Rick Trebino of Georgia Tech. A variety of femtosecond pulse shgaping techniques was discussed and the spatial effects of propagating such pulses in real media analysed, with particular emphasis on self-focusing and filamentation. The promising field of spatio-temporal dynamics is in its infancy, and new measures and definitions of spatial complexity and interaction are required. Propagation in the atmosphere generates quasi-stable filaments or "light strings" over hundreds of meters. Key immediate applications identified by the participants included communications, switching, data storage, precision machining, biomedical diagnostics and therapies, molecular and nanocluster dynamics.

Semiconductor laser dynamics

Although it has been forty years since semiconductor lasers were invented, they still present many fine mysteries and challenges at all levels from fundamental scientific understanding to mass production and engineering applications. The workshop began by considering the applications and their requirements, followed by the latest theories and experiments intended to overcome the challenges. Particular attention was paid to the necessity for many-body semiconductor physics, the benefits of quantum dots and type-II quantum wells, and the desirability of new materials such as GaInNAs for producing lasers in the telecommunications windows near 1300 and 1550 nm based on GaAs materials processing technologies. At the device level, key areas such as injection locking, mutual coupling, feedback dynamics and synchronization of chaotic lasers were explored, and spatio-temporal dynamics of large aperture lasers were described, with special emphasis on smoothing lateral gain and index profiles for maximum efficiency, stability and spatial coherence.

Acknowledgements

The organisers wish to thank the USAF and European Office of Aerospace Research and Development (EOARD) for their primary sponsorship of the workshop. Secondary sponsorship was provided by the Institute for Nonlinear Science and Science Foundation Ireland. The Trojan efforts of many people made the workshop successful, and while it is impossible to name them all it is appropriate to single out the administrative coordinators at either end: Ethan Deyo at the University of Arizona and Irene Horne at UCC.

Jerome V Moloney
John G McInerney

September 2001

Annex: technical programme and compendium of abstracts

PROGRAMME

DAY ONE: WEDNESDAY, 5 SEPTEMBER

8:45 -9:00am	Opening Remarks
9:00 - 10:00am	Plenary Speaker - Nicolaas Bloembergen (Arizona) *Historical Overview of Short Pulse laser Material Interactions*
10:00 - 10:30am	Margaret Murnane (Colarado) *Novel Phase Matching for EUV Generation*
10:30 - 11:00am	Craig W. Siders (CREOL) *Femtosecond X-Ray Diffraction Studies of Ultrafast Phase Transitions*
11:00 - 11:30am	Coffee Break
11:30 - 12:00	Rick Trebino (Georgia Tech) *Measuring Ultrashort Laser Pulses: Simple Devices and Complex Pulses*
12:00 - 12:30	Andrew Weiner (Purdue) *Ultrafast Pulse Shaping and Selected Applications in Linear and Nonlinear Photonics*
12:30 - 2:00pm	Lunch Break
2:00 - 2:30pm	John Reid (JDS Uniphase - Eindhoven) *Semiconductor Lasers in Communications*
2:30 - 3:00pm	Norbert Linder (OSRAM - Regensburg) *An Industry Perspective on High Power Diodes*
3:00 - 3:30pm	Kenton White (Nortel Networks - Ottawa) *Uncooled Semiconductor Lasers*
3:30 - 4:00pm	John G. McInerney (Cork) *Stabilising the dynamics of large aperture semiconductor lasers*
4:00 - 5:00pm	Coffee Break and Poster Session

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9:00 - 9:30am	Alex Gaeta (Cornel) *Supercontinuum Generation in Microstructured Fibers*
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11:00 - 11:30am	Coffee Break
11:30 - 12:00am	Roland Sauerbrey (Jena) *The Teramobile: Facility and First Experiments*
12:00 - 12:30pm	Jean Claude Diels (New Mexico) Nonlinear Propagation in Air: Simplifying both Theory and Experiment
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2:00 - 2:30pm	Andre Mysyrowicz (Paris Palaiseau) *Self-Guided Propagation of Intense Femtosecond Laser Pulse through the Atmosphere*
2:30 - 3:00pm	Jerome Moloney (Arizona) *Turbulent Atmospheric Light Strings and EMP from Plasma Tubes*
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4:00 - 4:30pm	Coffee Break
4:30 - 5:30pm	Panel Discussion: Perspectives on Femtosecond Pulse NLO

DAY THREE: FRIDAY, 7 SEPTEMBER

9:00 - 9:30am	Stephan Koch (Marburg) *Theory of Gain and Spontaneous Emission in Semiconductor Laser Structures*
9:30 - 10:00am	Martin Hofmann (Marburg) *Physics of 1.3mm (GaIn)(Nas)/GaAs Semiconductor Lasers*
10:00 - 10:30am	Miroslav Kolesik (Arizona) *Building Interactive Semiconductor Laser Simulation Tools from a Microscopic Basis*
10:30 - 11:00am	Yong-Hang Zhang (Arizona State University) *Type-II Quantum Well and Superlattice and their Applications in Semiconductor Lasers*
11:00 - 11:30am	Coffee Break
11:30 - 12:00am	Peter Blood (Cardiff) *Gain Characteristics of Quantum Dot Lasers: Potential for Ultrashort Pulse Generation*
12:00 - 12:30am	Weng Chow (Sandia) *Lasing in Type-II Quantum Wells*
12:30 - 2:00pm	Lunch Break
2:00 - 2:30pm	Ingo Fischer (Darmstadt) *Chaos Synchronization of Optically Coupled Semiconductor Lasers*
2:30 - 3:00pm	Athanasios Gavrielides (AFRL/DELO) *Regular and Low Frequency Fluctuation Dynamics in Semiconductor Lasers Subject to Delayed Feedback*
3:00 - 3:30pm	Thorsten Ackemann (Muenster) *Characteristic of Polarization Switching in VCSELs*
3:30 - 4:00pm	Coffee Break
4:00 - 4:30pm	Guillaume Huyet (Cork) *Current Profiling and Mode Control in Broad Area Lasers*
4:30 - 5:00pm	Ildar Gabitov (Los Alamos) *Pulse Dynamics in Optical Fibers with Randomly Varying Parameters*
5:00 - 5:30pm	Workshop Summary Discussion
7:30 - 10:00pm	**Workshop Dinner at Hayfield Manor**

SATURDAY, 8 SEPTEMBER - BUS DAY TRIP TO WEST CORK

DAY ONE: WEDNESDAY, 5 SEPTEMBER

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4:00 - 5:00pm	Coffee Break and Poster Session

Historical Overview of Short Pulse Laser Material Interactions

N. Bloembergen, Optical Sciences Center,University of Arizona,Tucson,AZ 85721

The development of pulsed lasers from the first ruby laser to the Ti-sapphire laser is briefly reviewed.Some historic experiments with picosecond laser pulses include transient raman scattering impulsive raman excitation in transparent materials.In absorbing materials picosecond pulses create a carrier plasma with subsequent heating,melting and evaporation on a timescale of about a hundred picoseconds.

With femtosecond pulses ten percent or more of the valence electrons in a tetrahedrally bonded semiconductor may be promoted to the conduction band before appreciable energy transfer to the lattice takes place.At such high electronic excitation the band structure changes on a time scale of less than ten femtoseconds and the bandgap may diminish to zero.The equlibrium lattice constant is changed and lattice vibrations are displacively excited.The band stucture and the complex index of refraction are modulated at this vibrational frequency.Electronic excitation of molecules at constant internuclear distance also to displacive excitations in the excited electronic state.Some paradigm examples of femtochemistry and femtobiology based on femtosecond pump-probe techniques will be presented.In transparent media intense femtosecond may create a high-density,high-temperature plasma by multiphoton absorption,amplified by avalanche ionisation in the trailing part of the pulse.Since so many electronic bonds are broken the material may acquire a higher index of refraction after the pulse.Nanojoule femtosecond pulses,focussed by an external microscope objective,can be used to create to write optical wave guide structures in transparent materials.

Concomitant with the measurement of shorter time intervals higher peak power flux densities have been achieved.With the chirped pulse amplification technique power flux densities exceeding milllions of terawatts/cm2 can be reached with a table-top laser facility.Electrons are accelerated to relativistic velocities in a quarter light cycle.
The propagation of [self]focussed femtosecond pulses with large spatial and temporal gradients in light intensity and plasma density is currently a very active field of investigation.
bonnnded

Novel Phase-Matching Techniques for EUV Generation

Randy A. Bartels, Sterling Backus, Ivan P. Christov, Henry C. Kapteyn, and Margaret M. Murnane
JILA, National Institute of Standards and Technology & University of Colorado, Boulder, CO 80309-0440
Ph: (303) 492-5637, FAX: (303) 492-5235, bartels@jila.colorado.edu

In the visible region of the spectrum, nonlinear conversion of light from one frequency to another is efficient because of phase matching. At visible frequencies, this is accomplished by propagating light through an appropriately-oriented anisotropic crystal. In this work, we present two new approaches—one experimentally-demonstrated, and the other proposed—that can be applied to the generation of light at short-wavelengths where solid nonlinear media cannot be used. The first demonstrates experimentally a phase matching process that can occur within a *single atom*. This technique applies quantum learning feedback control techniques to the process of high-harmonic generation, in effect controlling the evolution of an electron wavepacket to a precision of *25 attoseconds*. We demonstrate excellent agreement between theory and experiment. The second technique proposes to implement a new type of quasi phase-matching in the EUV based on *amplitude modulation.*

High-harmonic generation can be understood in a "recollision" model - an electron is first ionized and then recollides, with its parent ion, releasing its kinetic energy as an EUV photon. Repeated ionization and recollision events occur every 1/2 cycle of the pulse, and result in a train of x-ray bursts. In previous work, we demonstrated that properly shaped pulses can increase the brightness of a particular harmonic by >10 compared to a transform-limited pulse.[1] In this work, we demonstrate increases of >30, as shown in Fig. 1.

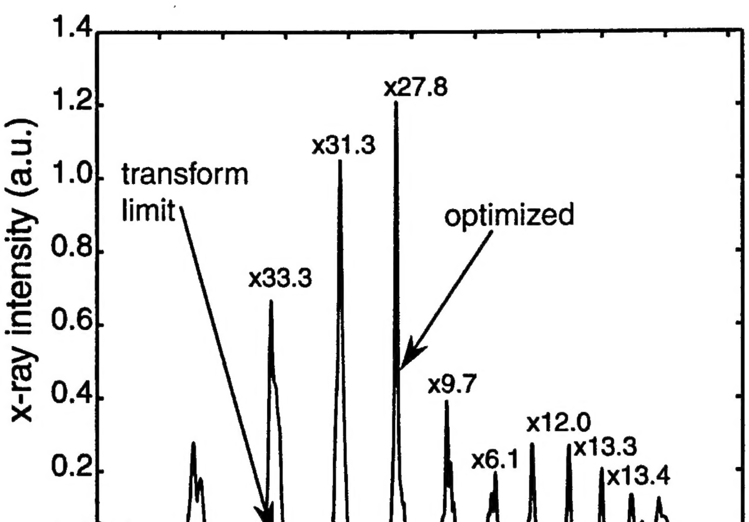

Fig. 1. Experimental optimization of the brightness of the 25th harmonic order. Because no selectivity is requested for this run, all harmonic orders increase for the optimal laser pulse, some by factors > 30.

The mechanism behind the enhancements observed can be explained as a new *single-atom* phase matching process.[2] Usually, the x-ray bursts generated by different 1/2 cycles of the laser pulse are not in phase, leading to destructive interference. By optimally shaping a light pulse with an appropriate nonlinear chirp, the phases of the x-ray bursts emitted from an atom during different half-cycles of the laser are re-aligned optimally to interfere constructively. This is shown in simulations illustrated in Fig. 2(a) for a transform limited pulse, and Fig. 2(b) for an optimized pulse. The *timing in the electron trajectories is adjusted by □ 25 attoseconds* to obtain constructive interference between the x-ray bursts resulting from different half-cycles of the laser field. This mechanism is different from traditional phase matching, because it does not depend on propagation.

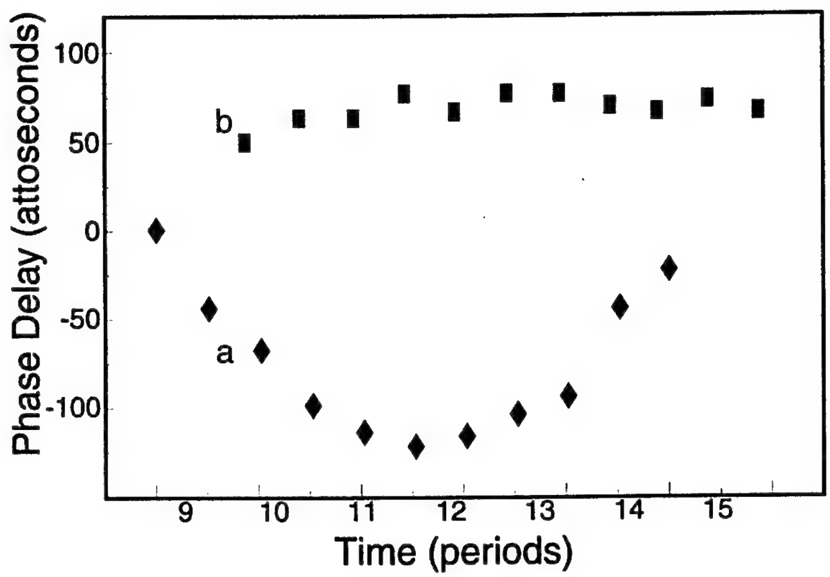

Figure 2: Phase of the target harmonics from different half-cycles of a transform limited (a) and optimized (b) laser pulse

The second phase matching mechanism we present relies on periodic amplitude modulation of the pump laser. This is accomplished using a modulated fiber with a period matching the coherence length of HHG.[3] Since cutoff harmonics are generated only at the highest intensities where the light is focused, QPM is achieved. A slight taper compensates for loss. An ~800x increase in EUV brightness is predicted.

[1] R. Bartels, S. Backus, E. Zeek, L. Misoguti, G. Vdovin, I. P. Christov, M. M. Murnane, and H. C. Kapteyn, "Shaped-pulse optimization of coherent emission of high-harmonic soft X-rays," *Nature*, vol. 406, pp. 164-166, 2000.

[2] I. P. Christov, R. Bartels, H. C. Kapteyn, and M. M. Murnane, "Attosecond time-scale intra-atomic phase-matching of high harmonic generation," *Physical Review Letters*, vol. 86, pp. 5458-5461, 2001.

[3] I. P. Christov, H. C. Kapteyn, and M. M. Murnane, "Quasi-phase matching of high-harmonics and attosecond pulses in modulated waveguides," *Optics Express*, vol. 7, pp. 362-367, 2000.

Femtosecond X-Ray Diffraction Studies of Ultrafast Phase Transitions

Myself and my colleagues in crime are:

Craig W. Siders, School of Optics/CREOL, Univ. of Central Florida, Orlando, USA

A. Cavalleri & Cs. Tóth, Lawrence Berkeley National Laboratory, Berkeley CA, USA

K.R. Wilson (posthumously) and J.A. Squier, Univ of California San Diego, USA

C.P.J. Barty, Lawrence Livermore National Laboratory, Livermore CA, USA

M. Kammler, University of Hannover, Germany

K. Sokolowski-Tinten, M. Horn von Hoegen, and D. von der Linde, Univ of Essen, Germany

Abstract

Photoinduced phase transitions in femtosecond-laser-irradiated crystalline materials are studied with time-resolved optical-pump femtosecond x-ray diffraction probe techniques. Ultrafast nonthermal melting, occurring on a time scale significantly faster than normal thermal melting, has been observed directly, for the first time, in thin Ge-111 films grown on Si-111 substrates by a novel surfactant mediated growth technique. Preliminary results in nonthermal solid-solid transitions in vanadium dioxide will also be discussed, as well as the study of anharmonic acoustic dynamics in thin Ge films.

"Measuring Ultrashort Laser Pulses: Simple Devices and Complex Pulses"

Dr. Rick Trebino

I describe recent developments in the complete measurement of ultrashort laser pulses using Frequency-Resolved Optical Gating (FROG). We have developed the world's simplest ultrashort pulse measurement device, requiring as little as a few square cm of table space and requiring no sensitive alignment. And we are also measuring the world's most complex ultrashort pulse, white-light continuum, whose time-bandwidth product exceeds 1000.

Ultrafast Pulse Shaping and Selected Applications in Linear and Nonlinear Photonics

A.M. Weiner

Purdue University

Ultrafast optical pulse shaping techniques allow programmable synthesis of nearly arbitrary ultrafast optical waveforms via wavelength-by-wavelength control of the complex optical spectrum [1,2]. This technology is now widely employed in ultrafast optical science, particularly for research on coherent control of quantum mechanical motions. Here I discuss pulse shaping from the perspective of applications in linear and nonlinear photonics. Topics include the following:

- Fourier transform femtosecond pulse shaping and its applications to programmable fiber dispersion compensation and to WDM.
- A new direct space-to-time (DST) pulse shaper, applicable to ultrafast optical parallel-to-serial converters offering the potential for operation at multi-GHz frame rates. We have implemented versions of the DST pulse shaper in both bulk optics and integrated optic arrayed waveguide grating technology. Interestingly, the DST pulse shaper geometry functions as a generalized spectrometer with a user definable and potentially highly structured spectrometer response function.
- New signal processing functionalities obtained by combining pulse shaping with nonlinear optics. Examples include a spectral nonlinear optics time-to-space (serial-to-parallel) converter and a novel spectral correlator for ultrafast waveform recognition based on implementing coherent control concepts in ultrafast second harmonic generation. In both examples, we highlight progress in performing ultrafast nonlinear optics at low power levels compatible with real-world photonics applications.

[1] A.M. Weiner, "Femtosecond optical pulse shaping and processing," Prog. Quantum Electron. **19** (3), 161-238 (1995).

[2] A.M. Weiner, "Femtosecond pulse shaping using spatial light modulators," Rev. Sci. Instr. **71**, 1929-1960 (2000).

Semiconductor lasers in communications.

Dr. John J.E. Reid,
JDS Uniphase Netherlands B.V., Prof Holstlaan 4, 5656 AA Eindhoven, The Netherlands, (john.reid@nl.jdsuniphase.com)

Abstract

The presentation will include a summary of the market forces relevant to the semiconductor laser industry in telecommunications. Their use in current systems will be depicted along with the migration paths to new systems with either evolutionary or disruptive technologies. The challenges associated with the deployment of semiconductor lasers in the network will be highlighted

An Industry Perspective on High Power Laser Diodes

N. Linder, J. Luft, M. Behringer, S. Groetsch

The market for high power laser diodes is rapidly increasing as Semiconductor lasers are both replacing traditional laser sources in, e.g., applications for materials processing or laser pumping, and allowing new applications due to their high efficiency, improved beam quality, small size and weight and their low cost.

This talk will give an overview of the issues to be considered when manufacturing high power lasers. Specifically, topics like cost and power, reliability, beam quality and mounting techniques will be discussed. Although high performance levels have been achieved, considerable work is spent on improving the laser characteristics further. These efforts have led to new trends and concepts. Some of the more recent developments, which are ready for commercialization, will be discussed.

Uncooled semiconductor lasers

J. K. White
Nortel Networks
High Performance Optical Component Solutions
3500 Carling Avenue
Ottawa, ON K2H 8E9
Canada

Temperature has always been the foe of semiconductor devices. It took the development of the double-heterostructure (cited for the 2000 Nobel Prize in Physics) to realize reliable room temperature semiconductor lasers. These devices still are sensitive to temperature changes and consequently require active cooling to assure their performance. As photonic applications become more cost sensitive it is becoming necessary to design devices that will work at high temperatures without a cooler. One recent evolution is the buried heterostructure laser, which prevents lateral current leakage at high temperature. A second advance is the development of semiconductor materials with a very large conduction band offset.

I will survey Nortel Network's recent uncooled semiconductor laser research. First I will discuss the high temperature limitations of current InGaAsP lasers. Then I will show how buried heterostructures and AlGaInAs lead to better temperature performance. Finally I will survey the future directions of uncooled semiconductor lasers.

Stabilizing the dynamics of large aperture semiconductor lasers

Prof. John G. McInerney

Abstract: large aperture (~100 um) semiconductor lasers are subtle, complex and extremely useful. After an initial introduction to these fascinating systems and their applications, we discuss the spatial and temporal dynamics of edge- and surface-emitting lasers capable of emitting ~1 W continuously. This talk will include some material which was originally intended for separate presentation by Dr James Walpole, formerly of MIT Lincoln Lab, Lexington, Mass., USA.

DAY TWO: THURSDAY, 6 SEPTEMBER

9:00 - 9:30am	Alex Gaeta (Cornel) *Supercontinuum Generation in Microstructured Fibers*
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11:00 - 11:30am	Coffee Break
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12:00 - 12:30pm	Jean Claude Diels (New Mexico) Nonlinear Propagation in Air: Simplifying both Theory and Experiment
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3:30 - 4:00pm	Olga Kosareva (Moscow) *Simulation of Femtosecond Laser Pulse Propagation in Air: Conical Emission phenomenon, stochastic filamentation*
4:00 - 4:30pm	Coffee Break
4:30 - 5:30pm	Panel Discussion: Perspectives on Femtosecond Pulse NLO

Supercontinuum generation in microstructured fibers

Dr. Alex Gaeta

Abstract

We investigate the propagation of femtosecond pulses in microstructured fibers under conditions in which supercontinuum radiation is generated. The generation of this white-light spectrum with nanojoule pulses is responsible for recent advances in frequency metrology and in optical coherence tomography. In our studies, we find that higher-order dispersion primarily determines the shape and width of the generated supercontinuum spectrum and we discuss designs of microstructured fibers that would allow one to optimize the spectral shape.

Compression of Ultrafast Optical Pulses using Rotational Phase Modulation

R. A. Bartels, T. C. Weinacht, N. Wagner, M. Baertchy, C. Greene,M. M. Murnane, and H.C. Kapteyn

JILA, National Institute of Standards and Technology & University of Colorado, Boulder, CO 80309-0440
Ph: (303) 492-5637, FAX: (303) 492-5235, bartels@jila.colorado.edu

Gas-phase molecules subjected to intense ultrashort light pulses exhibit a complex time-dependent nonlinear response that exhibits well-behaved quantum rotation wavepacket revivals. We characterize this nonlinear response in a number of molecular species. Using this data and theoretical models, we demonstrate for the first time that this time-dependent phase modulation can be used to manipulate the phase and spectral content of ultrashort light pulses in unique and desirable ways.[1] By impulsively exciting a rotational wave packet in CO_2, we increase the bandwidth of a probe pulse by a factor of 3.8, while inducing a negative chirp. This negative chirp is then removed by propagation through a fused silica window, without the use of a pulse compressor. This is a very general technique for ultrafast pulse compression, and can be applied over a broad spectral region throughout the IR, visible and UV.

[1] R. A. Bartels, T. C. Weinacht, N. Wagner, M. Baertchy, C. Greene, M. M. Murnane, and H. C. Kapteyn, "Phase Modulation of Ultrashort Light Pulses using Molecular Rotational Wavepackets," *Physical Review Letters*, Submitted, 2001.

Intensity clamping of a femtosecond laser pulse in optical media

A.Becker[1], K. Vijayalakshmi[1], E. Oral[1], W. Liu[1], S. Petit[1],
N. Aközbek[2], C.M. Bowden[2] and S.L. Chin[1]

[1] *Centre de Optique, Photonique et Laser (COPL) and Département de physique, de génie physique et d'optique, Université Laval, Québec, QC, Canada G1K 7P4*
[2] *U.S. Army Aviation and Missile Command, AMSAM-WS-RD-ST, Huntsville, AL 25898-5000, USA*

We have investigated the phenomenon of intensity clamping during the propagation and filamentation of a high-power Ti :sapphire laser in different optical media. First, we have measured fluorescence spectra due to the interaction of the laser pulse with nitrogen molecules at different gas pressures. Characteristic changes of the slope of the signal as a function of the pulse energy are found to depend on the gas pressure. At high gas pressures, these characteristic changes are identified as due to intensity clamping and refocusing of the pulse. The laser pulse energy for intensity clamping as a function of the gas pressure is determined. The analysis of the experimental data is found to be in qualitative agreement with results of numerical simulations using a pulse propagation model. We have further measured the supercontinuum spectrum of the Ti :sapphire laser pulse propagating in condensed media (water, chloroform and glass), at various input laser energies below and above the threshold for filamentation of the laser pulse. It is found that the maximum positive frequency shift of the supercontinuum spectrum remains constant at pulse energies that generate single and mutiple filamentation. The constant shift is identified as due to the clamping of the peak intensity inside the filaments.

Femtosecond Measurement of Two-Photon Absorption at λ = 264 nm in Liquids, Glasses and Crystals.

Adrian Dragomir, John G. McInerney, David N. Nikogosyan
Physics Department and Institute for Nonlinear Science, National University of Ireland, University College Cork, Cork, Ireland

Abstract

With the development of high-intensity UV lasers the studies of two-photon absorption (TPA) become actual. The knowledge of TPA coefficient β in the ultraviolet range is important for estimation of intensity-dependent losses when modelling the laser systems and/or frequency converters. On the other hand, the appearance of UV laser sources, generating femtosecond pulses with high irradiance stability, allows determination of TPA coefficient with total accuracy of about 10% unavailable before. In our research we employed a newly developed laser system (Twinkle, Light Conversion Ltd, Lithuania) which produces ultraviolet femtosecond pulses (λ = 264 nm, E = 200 μJ, τ = 220 fs, □f = 27 Hz) with energy stability of 10%. Using nonlinear transmittance approach we have studied the TPA coefficient in a number of liquids: water, heavy water, ethanol, methanol, hexane, cyclohexane, 1,2-dichloroethane and chloroform. The corresponding β values were found to be between $(34\pm3)\times10^{-11}$ cm/W and $(95\pm11)\times10^{-11}$ cm/W. We have measured the TPA coefficient in three fused silica samples Suprasil, Herasil, Infrasil (Heraeus) and in Ge-doped fused silica, commonly used in fiber Bragg gratings production. While in fused silica samples the β value is about 2×10^{-11} cm/W, in 3.5 mol % germanosilicate glass it equals to $(51 \pm 3) \times10^{-11}$ cm/W. For crystalline quartz and sapphire cut perpendicular to the optical axis, the following β values were obtained: $(1.0\pm0.1)\times10^{-11}$ cm/W and $(9.4\pm0.9)\times10^{-11}$ cm/W, respectively. For BBO crystal it was found that nonlinear absorption depends significantly on crystal cut and/or beam polarisation. For an ordinary beam propagating along the optical axis ($\parallel c$) and perpendicular to it ($\perp c$) the similar values of TPA coefficient were obtained, namely $(68 \pm 6) \times 10^{-11}$ cm/W and $(66 \pm 7) \times 10^{-11}$ cm/W. For an extraordinary beam ($\perp c$) the TPA coefficient is significantly smaller, $(47 \pm 5) \times 10^{-11}$ cm/W.

The Teramobile: Facility and First Experiments

Roland Sauerbrey[1], Y.-B. André[2], M. Franco[2], T. Fujii[3], N. Galace[4], J. Kasparian[4], D. Mondelain[4], A. Mysyrowicz[2], B. Prade[2], M. Rodriguez[1], E. Salmon[4], S. Tzortzakis[2], H. Wille[3], J.-P. Wolf[4], L. Wöste[3], J. Yu[4]

[1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany, Phone: +49 3641 947200, Fax:+49 3641 947202, e-mail: sauerbrey@ioq.uni-jena.de

[2]École Polytechnique - ENSTA, Laboratoire d'Optique Appliquée, Unité Inserm U-275, Batterie de l'Yvette, 91120 Palaiseau, France

[3]Freie Universität Berlin, Institut für Experimentalphysik, Arnimallee 14, 14195 Berlin, Germany

[4]Laboratoire de Spectrometrie Ionique et Moleculaire, Universite Claude Bernard Lyon 1, 43, Bd du 11 Novembre 1918, 69622 Villeurbonne Cedex, France

Abstract:

A mobile TW laser facility combined with a detection unit was constructed. It consists of a 4 TW (350 mJ, 80 fs) compact Titanium:Sapphire laser that is housed in a standard Euro container together with a control unit, sending and receiving optics for the laser beam and lidar signals as well as diagnostics equipment.

First experiments with this novel facility concentrated on propagation of intense laser pulses in the atmosphere and the investigation of the electrical conductivity of light channels produced by the TW laser. At the high-voltage facility at the Technische University Berlin it was shown that discharges of 4 m length are guided along the laser beam. For laser energies exceeding 30 mJ such discharges are initiated by the laser even at voltages which are not sufficient to lead to spontaneous air breakdowns.

Nonlinear propagation in air: simplifying both theory and experiment

Jean-Claude Diels and Jens Schwarz
Department of Physics and Astronomy and
Center for High technology Materials
1313 Goddard S.E.
Albuquerque, NW 87106
jcdiels@unm.edu
(505) 277 4026 (Fax and Phone)
(505) 272 7830 (phone)

ABSTRACT

The catastrophic collapse of a large diameter beam above critical power is indeed ... a catastrophic event. It is therefore very elusive to both theoretical and experimental investigation. We show that physical conditions can be selected which lead to comsiderably better control for both the experimental and theoretical analysis. A analytical solution for the UV filamentation is presented.

Self-Guided Propagation Of Intense Femtosecond Laser Pulses Through Atmosphere

A. Mysyrowicz, S. Tzortzakis, Y-B. André, M. Franco, B. Prade

Laboratoire d'Optique Appliquée, Centre National de la Recherche Scientifique, Ecole Nationale Supérieure de Techniques Avancées - Ecole Polytechnique, Chemin de la Huniére, F-91761 Palaiseau Cedex, France

Intense femtosecond laser pulses launched in atmosphere self-organise into filaments which can subsist over long distances. We discuss the physical origin of this effect . Experimental results concerning IR and UV pulse filamentation are compared to numerical simulations. Application of filaments to the formation of a conductive air channel are described

Turbulent Atmospheric Light Strings and EMP from Plasma Tubes

J.V. Moloney, M. Kolesik and E.M. Wright
Arizona Center for Mathematical Sciences
and
Optical Sciences Center
University of Arizona, Tucson AZ 85721

The breakup of high power femtosecond-duration laser pulses propagating in air into a sea of interacting self-focusing light strings and accompanying narrow plasma tubes involves the rich interplay of a broad spectrum of physical processes. Explosive self-focusing involves dramatic compression of individual light strings down to diameters of 80-100 μm before multi-photon dominated optical breakdown generates narrow plasma tubes that act as optical limiters. Self-focusing generated supercontinuum radiation is further modified by strong plasma generated blue-shifted spectrum. The plasma itself can recombine on a much slower timescale than the transient optical pulse and emit an intense burst of RF/microwave radiation.

We will review the current state of our research into this complex ultrafast nonlinear optical phenomenon. The qualitative aspects of light string formation and interaction can be captured by a generalized 3D Nonlinear Schrödinger equation model. There has been considerable discussion in the literature recently with regard to the importance of higher order correction terms to the NLS equation for femtosecond pulse propagation in air and condensed media. We will present a general 3D vectorial model, derived form Maxwell's equations, that accurately describes forward pulse propagation with all relevant higher order physical interactions included. Recent envelope and non-envelope approaches will be compared.

Self-Focusing, Filamentation, and White-Light Continuum Generation of Ultra-Short Laser Pulses in Air

C. M. Bowden, N. Akozbek, M. Scalora
U. S. Army Aviation and Missile Research, Development and Engineering Center
U. S. A.

And

S. L. Chin
Photonique et Laser and Departement de Physique, Centre d'Optique, Universite Laval
Quebec City, Quebec, Canada

Abstract

Numerical results are presented for propagation of femtosecond pulses in air including multiphoton ionization, group-velocity dispersion, space-time focusing, self-steepening, Raman response, and higher order chi5 defocusing. It is shown that the self-steepening terms cause strong blue shift of the spectrum, thus generating a white-light continuum. Our results are shown to be in good agreement with experimental observations. In addition, we discuss numerical and experimental results that reveal signatures of intensity clamping and refocusing of the laser pulses and the pulse energy for intensity clamping as a function of gas pressure is presented. Further, experimental and numerical results are exhibited for ring structure formation and third harmonic generation is discussed. Finally, a variational analytic analysis is presented from which qualitative physical interpretation is provided for interpretation of experimental and numerical simulations, and to guide experiments and theoretical development.

Simulations of femtosecond laser pulse propagation in air: conical emission phenomenon, stochastic filamentation

V.P.Kandidov, O.G.Kosareva, S.A. Shlenov, I.S. Golubtsov

International Laser Center, Department of Physics, Moscow State University, 119899, Moscow, Russia,

tel: +7 (095) 939-3091, fax +7 (095) 939-3113, e-mail: kosareva@msuilc.ilc.msu.su

Long light filaments are produced when a femtosecond laser pulse with peak power $5\text{x}10^9$- $2\text{x}10^{12}$ W propagates through air. This propagation is accompanied by white light conical emission, pulse splitting, refocusing, transverse spatial ring formation [1-4]. These processes are the result of spatio-temporal transformation of the pulse in the conditions of strong nonlinear-optical interaction between the radiation, neutral air molecules and laser-induced plasma [5].

In the natural atmospheric conditions filamentation is a stochastic process. The evidence for this fact is random displacements of the filament center from shot to shot in the plane perpendicular to the propagation direction [4]. In the pulses with terawatt peak power a bunch of filaments is created [3]. The number of filaments in the bunch changes randomly from one laser shot to another [6]. One of the reasons for stochastic behaviour of filaments is random fluctuations of refractive index in the turbulent air.

In this paper we present the generalized stochastic model of filamentation and supercontinuum conical emission. The detailed explanation of the conical emission generation is given. The effect of atmospheric turbulence and partial coherence of the laser radiation on the filament formation is demonstrated.

1. Generalized stochastic model

The propagation equation for the slowly varying amplitude of the electric field $E(x,y,z,t)$ is given by

$$2ik_0\left(\frac{\partial}{\partial z}+\frac{1}{v_g}\frac{\partial}{\partial t}\right)E=\Delta_\perp E-k\frac{\partial^2 k}{\partial\omega^2}\frac{\partial^2 E}{\partial t^2}+i\left(\frac{1}{v_g}\frac{\partial^2 k}{\partial\omega^2}+\frac{1}{3}k\frac{\partial^3 k}{\partial\omega^3}\right)\frac{\partial^3 E}{\partial t^3}+2k^2\Delta n_{nl}(E)E+2k^2\tilde{n}_{turb}(x,y,z)E-ik_0\alpha E, \quad (1)$$

where the nonlinear part of the refractive index $\Delta n_{nl}=\Delta n_{pl}+\Delta n_k$ takes into account the contribution from the plasma and from both instantaneous and delayed parts of cubic nonlinearity. The value $\tilde{n}(x,y,z)$ describes random fluctuations of the refractive index in turbulence, coefficient α is responsible for the ionization energy loss. The terms with $\frac{\partial^2 k}{\partial\omega^2}, \frac{\partial^3 k}{\partial\omega^3}$ take into account material dispersion in air in the second and the third order approximation. The ionization rate is calculated according to the PPT formula with the effective charge chosen so as to fit the experimental data obtained in the experiment [7]. Refractive index fluctuations in the atmospheric turbulence are described by the Kolmogorov-Karman-Tatarskii model [8], according to which the spatial spectrum is given by

$$\Phi_n(\kappa)=0{,}033C_n^2(\kappa^2+\kappa_0^2)^{-11/6}\exp\{-\kappa^2/\kappa_m^2\},\ \kappa_0=2\pi/L_0,\ \kappa_m=5.92/l_0, \quad (2)$$

where L_0 and l_0 are the outer and the inner scales of turbulence, respectively.

This spectrum allows us to simulate a wide range of spatial scales, which change from one millimeter to several meters in the turbulent air.

The slowly varying amplitude of the electric field in the input pulse is given by:

$$E(x,y,z=0,\tau)=\tilde{\eta}(x,y)E_0\exp\left\{-\frac{x^2+y^2}{2a_0^2}\right\}\exp\left\{-\frac{\tau^2}{2\tau_0^2}\right\}, \quad (3)$$

where $\tilde{\eta}(x,y)=\tilde{\xi}(x,y)+i\tilde{\varsigma}(x,y)$ is a Gaussian noise with $\langle\tilde{\xi}(x,y)\tilde{\varsigma}(x,y)\rangle=0$. The correlation function of the noise is given by $B_\xi(x,y)=B_\varsigma(x,y)=\sigma^2\exp\left\{-\frac{x^2+y^2}{r_k^2}\right\}$, the variance of the noise is $\sigma^2=0.5$.

2. Phenomenon of the conical emission

The study of the conical emission phenomenon was performed with fully coherent laser beam in the medium without atmospheric turbulence. The pulse propagation was described by the Eq. (1) with $n_{turb}(x,y,z)$

= 0. In the initial intensity distribution given by Eq. (3) the value $\tilde{\eta}(x, y)$ was set to 1. We have demonstrated that conical emission originates from self-phase modulation in the conditions of high spatial and temporal localization of the electric field in the filament. Temporal changes in the phase distribution cause broadening of the frequency spectrum. Changes of the phase distribution in the transverse direction cause broadening of the angular spectrum.

Frequency-angular spectrum of the conical emission results from many factors including the character of cubic nonlinear response, the dynamics of free electron generations in the strong laser field, material dispersion. These factors could affect the values of the conical emission angles and wavelengths in the opposite directions. Careful consideration of all the factors in our model allowed us to obtain quantitative agreement with the experiment.

3. The model of stochastic filamentation

Study of stochastic filamentation was performed in the turbulent medium with partially coherent laser beam. Plasma contribution and material dispersion were neglected, because we considered only initial stage of the filament formation. Initial intensity distribution was given by Eq. (3). Numerical simulations demonstrated that perturbations of the radiation wavefront in the turbulent atmosphere cause random displacements of the filament formation point in the longitudinal direction and fluctuations of the filament center position in the transverse plane. The origin of random filament center displacements may be both the perturbations of the light field of the initial laser beam and beam wavefront distortions in the turbulent atmosphere. We demonstrated the breakup of intensity distribution symmetry in the course of stochastic filamentation. Careful experimental measurements and numerical simulations are required to find out what is responsible for the filament center displacements – atmospheric turbulence or imperfect beam quality. This is a crucial question for the multifilamentation of femtosecond terawatt pulses.

References

1. Braun A., Korn G., Liu X., Du D., Squier J., and Mourou G., *Opt. Lett.*, **20**, 73, (1995)
2. Nibbering E.T.J., Curley P.F., Grillon G., Prade B.S., Franco M.A., Salin F., and Mysyrowitcz A., *Opt. Lett.*, **21**, 62, (1996)
3. Woste L., Wedekind C., Wille H., Rairoux P., Stein B., Nikolov S., Werner Ch., Niedermeier St., Ronneberger F., Shillinger H., and Sauerbrey R., *Laser and Optoelectronik*, **29**(5), 51, Oktober, (1997)
4. Brodeur A., Kosareva O.G., Chien C.Y., Ilkov F.A., Kandidov V.P., and Chin S.L., *Opt. Lett.*, **22**, 304, (1997)
5. Mlejnek M., Wright E.M., and Moloney J.V., *Opt. Lett.* **23,** 382, (1998)
6. Fontaine B.L., Vidal F., Jiang Z., Chien C.Y., Corntois D., Desparois A., Jonston T.VW, Kieffer J-c., Pepin H., Mercure H.P., *Physics of Plasmas* **6,** 1815 (1999)
7. Talebpour A., Yang J., Chin S.L., *Opt. Comm.*, **163**, 29 (1999).
8. A. Ishimaru, *Wave Propagation and Scattering in Random Media,* New York, Academic Press, 1978.

DAY THREE: FRIDAY, 7 SEPTEMBER

9:00 - 9:30am	Stephan Koch (Marburg) *Theory of Gain and Spontaneous Emission in Semiconductor Laser Structures*
9:30 - 10:00am	Martin Hofmann (Marburg) *Physics of 1.3mm (GaIn)(Nas)/GaAs Semiconductor Lasers*
10:00 - 10:30am	Miroslav Kolesik (Arizona) *Building Interactive Semiconductor Laser Simulation Tools from a Microscopic Basis*
10:30 - 11:00am	Yong-Hang Zhang (Arizona State University) *Type-II Quantum Well and Superlattice and their Applications in Semiconductor Lasers*
11:00 - 11:30am	Coffee Break
11:30 - 12:00am	Peter Blood (Cardiff) *Gain Characteristics of Quantum Dot Lasers: Potential for Ultrashort Pulse Generation*
12:00 - 12:30am	Weng Chow (Sandia) *Lasing in Type-II Quantum Wells*
12:30 - 2:00pm	Lunch Break
2:00 - 2:30pm	Ingo Fischer (Darmstadt) *Chaos Synchronization of Optically Coupled Semiconductor Lasers*
2:30 - 3:00pm	Athanasios Gavrielides (AFRL/DELO) *Regular and Low Frequency Fluctuation Dynamics in Semiconductor Lasers Subject to Delayed Feedback*
3:00 - 3:30pm	Thorsten Ackemann (Muenster) *Characteristic of Polarization Switching in VCSELs*
3:30 - 4:00pm	Coffee Break
4:00 - 4:30pm	Guillaume Huyet (Cork) *Current Profiling and Mode Control in Broad Area Lasers*
4:30 - 5:00pm	Ildar Gabitov (Los Alamos) *Pulse Dynamics in Optical Fibers with Randomly Varying Parameters*
5:00 - 5:30pm	Workshop Summary Discussion
7:30 - 10:00pm	**Workshop Dinner at Hayfield Manor**

SATURDAY, 8 SEPTEMBER - BUS DAY TRIP TO WEST CORK

Microscopic Theory of Gain and Spontaneous Emission in Semiconductor Laser Structures

S.W. Koch, Univ. Marburg/Germany
J. Hader & J. V. Moloney, Univ. Arizona, Tucson

Abstract

Gain/absorption and spontaneous emission of semiconductor laser structures is computed combining a microscopic theory for the Coulomb interacting electron-hole plasma with k.p bandstructure calculations for the heterostructures. Comparisons with recent experiments are presented for a variety of different material and device configurations.

Physics of 1.3 μm(GaIn)(NAs)/GaAs Semiconductor lasers

Martin R. Hofmann
Fachbereich Physik und Wissenschaftliches Zentrum für Materialwissenschaften der Philipps-Universität, Renthof 5, D-35032 Marburg, Germany
Phone: (+49) 6421 2824156
(+49) 6421 2827036
e-mail: Martin.Hofmann@physik.uni-marburg.de

The new material system (GaIn)(NAs) is a promising candidate for GaAs-based vertical-cavity surface-emitting lasers (VCSELs) in the wavelength ranges of 1300 and 1550 nm. (GaIn)(NAs)/GaAs edge emitting lasers with emission wavelengths up to 1520 nm were demonstrated, optically and electrically pumped VCSEL-structures at 1300 nm have been realized in combination with GaAs/AlAs Bragg reflectors. However, little is still know about the physics of the light emission in (GaIn)(NAs)/GaAs. We investigate the emission dynamics of 1300 nm (GaIn)(NAs)/GaAs VCSELs and the optical gain in this new material system.
Firstly, we study experimentally the emission dynamics of an optically pumped MOCVD-grown 1300 nm (GaIn)(NAs)/GaAs VCSEL with a particular focus on the temperature dependence of the emission. The dynamics at room temperature are in the picosecond range (peak delay-time of 15.5 ps after excitation and pulse width of 10.5 ps). Moreover, we find laser emission with picosecond dynamics for temperatures between 30 K and 388 K . The measured band gap shift with temperature of -0.29 meV/K cannot explain the enormous temperature operation range observed for the VCSEL alone. Therefore we additionally studied the optical gain spectra of (GaIn)(NAs). The gain spectra were measured for a MBE-grown ridge-waveguide edge-emitting structure using the method by Hakki and Paoli and the transmission method. We compare our gain spectra with calculations based on a microscopic model for perfect quantum wells that does not require any phenomenological homogeneous broadening parameters. However, we introduce an *inhomogeneous* broadening of 18 meV in order to account for broadening of the spectra due to disorder. and/or imperfections of the crystal that are not part of the microscopic calculation. A comparison of measured and calculated gain spectra for our (GaIn)(NAs) - quantum well structure is shown in Fig.1.

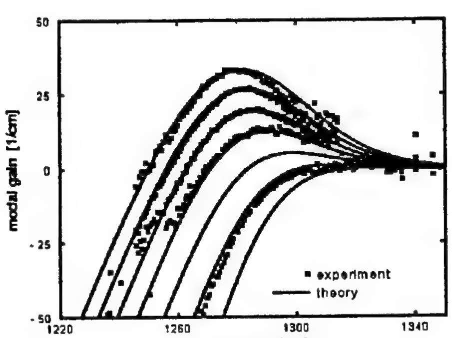

Fig.1. Comparison of experimental and theoretical gain spectra.

The very good agreement shows that our sample is well described by an inhomogeneously broadened quantum well system. We also compare experimental and theoretical gain spectra for elevated carrier densities and find again excellent agreement. Finally, we implemented our gain model into a modeling of the temperature dependent VCSEL emission. The model calculations reproduce very well the enormous temperature operation range observed experimentally.

Building Interactive Semiconductor Laser Simulation Tools from a Microscopic Basis

M. Kolesik, M. Matus and J.V. Moloney
Arizona Center for Mathematical Sciences
And
Optical Sciences Center
University of Arizona, Tucson, AZ 85721

Semiconductor lasers provide very large gain in small volumes over broad frequency ranges spanning multiple THz. Microscopic many-body calculations have proved so reliable in computing gain and refractive index spectra as a function of carrier density, lattice and plasma temperature, that realistic and quantitative simulation of semiconductor amplifier and laser structures is now feasible. Capturing the complex gain/index shapes that can change significantly over a multi-dimensional parameter landscape offers a major computational challenge.

We will report on a highly efficient and fast algorithm that allows us to simulate both 1D and 2D semiconductor amplifier/laser structures in real time on a fast PC and in parallel, on a multiprocessor supercomputer, respectively. Specific applications that highlight the overall power and flexibility of this approach will be presented.

Type-II Quantum Well and Superlattice and their Applications in Semiconductor Lasers

Y.-H. Zhang
Center for Solid State Electronics Research & Department of Electrical Engineering
Arizona State University, Tempe, AZ 85287
Email: yhzhang@asu.edu

The effective band gap of a type-II heterostructures, such as quantum well (QW) or superlattice (SL), is determined not only by the band gaps of the constituent materials but also by their heterojunction bandedge alignment. Therefore, an effective band gap of a type-II QW or SL can be smaller than that of any of the constituent materials. Such an interesting property of type-II heterostructures has been successfully used in semiconductor lasers, which has enabled the "band gap engineering" to reach longer wavelengths.

In this talk, I will summarize various III/V type-II heterostructures grown on different substrates, covering the near IR and midwave IR wavelength ranges. Strong emphasis will be put on our latest theoretical modeling and experimental research on the GaAsSb(P)/(In)GaAs type-II QW lasers grown on GaAs substrates.

Gain characteristics of quantum dots lasers: potential for ultra-short pulse generation.

Peter Blood, Peter Smowton and Huw Summers
Department of Physics and Astronomy, Cardiff University,
PO Box 913, Cardiff CF24 3YB, UK

Semiconductor materials are, in principle, well-suited to short pulse generation because the bands of states produce a broad gain spectrum. However it has proved difficult to realise the full theoretical potential of this bandwidth possibly because of homogeneous broadening. Quantum dots provide an ensemble of spatially localised electronic states with substantial inhomogeneous broadening due to variations in physical size and these structures may offer a better route to realisation of ultra short pulse diode lasers. We report an experimental investigation of the width of the quantum dot gain spectrum, and extent to which the dots behave as an inhomogeneously broadened ensemble of states.

Measurements of modal gain (G) of single layer of InGaAs dots using a segmented contact technique reveal gain spectra spanning about 100nm at room temperature. The width increases with increasing injection current and decreases with decreasing temperature. The latter observation suggests there is a significant thermal contribution to the width in addition to any inhomogeneous broadening. To investigate the nature of the energy distribution of occupied dot states we also measured true spontaneous emission spectra (R_{sp}) using segmented contact structures with a window in the top contact. We obtained experimental data for the ratio of local gain (g) to spontaneous emission rate at each photon energy:

$$P_f' = \left(\frac{g}{R_{sp}}\right) = C\left\{\frac{\pi^2\hbar^3c^2}{n^2(h\nu)^2}\right\}P_f$$

where P_f is the population inversion factor and C is a constant which takes account of the fact that R_{sp} is measured in arbitrary units. In general, the inversion factor is given by

$$P_f = \left[\frac{f_c - f_v}{f_c(1-f_v)}\right]$$

where f_c and f_v are general occupation probabilities of the upper and lower states. For the *particular case* of a thermal Fermi-Dirac distribution P_f can be calculated in terms of the quasi Fermi level separation. We have compared experimental spectra for P_f' with calculated values for P_f for a thermal distribution using appropriate experimental values for the Fermi level separation. Between 100K and 300K the quantum dots behave like a homogeneously broadened system in which the states are occupied according to Fermi-Dirac statistics. However, at 70K the behaviour departs drastically from that of a thermal distribution, with inversion being achieved only for the uppermost transition energies. This has been confirmed by hole-burning experiments which will also be described. The energy distribution of electrons in dot systems is dependent upon the rates of the mediating processes and we have yet to determine the characteristics of these distributions at recombination rates which correspond to stimulated emission under lasing conditions in order to obtain a complete picture regarding the use of dots for short pulse generation.

We thank EPSRC for financial support, and Eugen Herrmann, John Thomson, Dan Matthews and Paul Hulyer, all at Cardiff, for their contributions to this work.

Lasing in type-II quantum wells

Dr. Weng Chow

Abstract

Semiconductor gain media in the 1.3 to 1.5 micron wavelength range are currently under intense investigation, because of the important role of lasers in optical fiber communications. For vertical-cavity surface-emitting lasers (VCSELs), gain structures that can be epitaxially grown on GaAs substrates are of particular interest.

One such system is the Sb-based type-II quantum-well. The defining feature of a type-II quantum well is the spatial separation of electron and hole confinement in the epitaxial growth direction. Because of the charge separation, a type-II quantum-well structure can exhibit interesting excitation-dependent optical behaviors due to the competing effects of quantum confinement, which separates the electron and hole distributions, and the resulting Coulomb attraction, which induces band distortions that have the opposite effect of increasing their overlap. This talk describes an investigation of the interplay of these effects, which can lead to strong carrier density dependences in the oscillation strength and bandedge energies.

Implications to laser operation, including the large blue shift in gain peak with increasing injection current, and inhibition of spontaneous emission, will be discussed.

Chaos-Synchronization of Optically Coupled Semiconductor Lasers

Dr. Ingo Fischer

Abstract

The investigation of optically coupled semiconductor laser systems provides new insights into fundamental phenomena of coupled nonlinear systems, and furthermore offers perspectives for the realization of novel encoded data transmission schemes based on chaotic carriers. In the center of our interest is the possibility of synchronization of fast chaotic oscillations in the emission of semiconductor lasers which we could recently demonstrate. It can either be realized when the emission of a chaotic laser is unidirectionally coupled into a second twin system, or when two similar lasers are coupled by mutual optical injection. In the latter case the chaotic emission is even induced by the coupling which at the same time is responsible for the synchronization. Consequences and implications of chaos-synchronization with respect to fundamental phenomena and novel applications will be discussed.

"Regular and low frequency fluctuation dynamics in semiconductor lasers subject to delayed feedback"

Dr. Athanasios Gavrielides

<u>Abstract</u>

Temporally resolved investigations of the dynamics of semiconductor lasers subject to delayed optical feedback from short external cavities will be presented. Experimental and numerical evidence show a novel dynamics phenomenon: periodic low frequency fluctuation locked states corresponding to trajectories along well defined looped channels covering several external cavity attracttors within the complicated phase space structure of this delay system.

Characteristics of polarisation switching in VCSELs

T. Ackemann, M. Sondermann

Institut fuer Angewandte Physik, Westfaelische Wilhelms-Universitaet Muenster, Corrensstrasse 2/4, 48149 Muenster, Germany
Email: t.ackemann@uni-muenster.de

Polarisation selection in vertical-cavity surface emitting lasers is studied experimentally in dependence of injection current and substrate temperature in the vicinity of the minimum threshold condition. A particular focus is on polarisation switching from the low to the high frequency fundamental polarisation mode. The observation of dynamical transition states hints to the relevance of nonlinear effects. A comparison to the predictions of the SFM-model based on spin degrees of freedom and phase-amplitude coupling is given.

Current profiling and mode control in broad area lasers

Guillaume Huyet

University College Cork

We analyse the coherence properties of high power semiconductor lasers with a modified transverse current profile. Our experimental investigations are based on conventional stripe geometry high power edge emitting devices incorporating an extra p type spreading layer to smooth the carriers from the usual top hat injection profile. We also use the a lithographic half tone technique to achieve the desired injection profile. Current profiling could also be implemented in vertical cavity lasers with proton implementation or inhomogeneous optical pumping.

In these devices the near-field is similar to the current profile while the far-field shows a double peak demonstrating off-axis emission. We will demonstrate, both experimentally and theoretically, that such a behaviour is associated with the presence of a single transverse mode.

Pulse dynamics in optical fibers with randomly varying parameters

Dr. Ildar Gabitov

Abstract

Randomness of fiber parameters seriously limits the capacity of high bit-rate optical transmission links that require short optical pulses as a bit carriers. We will consider the main sources of randomness, and its impact on optical pulse dynamics. In addition to pulse deterioration, random variation of fiber characteristics causes interaction between pulses in a data stream by continuous shedding of radiation. A new method that in several cases is capable of preventing pulse deterioration and minimizing the negative impact of pulse interaction will be also discussed.

POSTER PRESENTATION ABSTRACTS

Wednesday 5 September 2001 at 4 p.m.

Venue

Council Room

North Wing

Main Quadrangle

Ultrashort light-pulse propagation -- Are "corrected" envelope equations necessary and sufficient?

M. Kolesik and J.V. Moloney
Arizona Center for Mathematical Sciences
and
Optical Sciences Center
University of Arizona, Tucson
AZ 85721

While the use of slowly varying envelope equations is common in nonlinear optics, indications appear in the recent literature that in certain situations it is necessary to include various "correction terms" that improve the basic equation in order to describe correctly some effects, such as supercontinuum generation in the collapse of ultrashort pulses [A. Gaeta, PRL 84 (2000) 3582].

The corrected equations are usually derived in the amplitude-envelope Framework and originate in the wave equation [see e.g. Brabec and Krausz, PRL 78 (1997) 3282].

The correction terms arise in the form of additional partial derivative terms or pseudodifferential operators that represent a partial "perturbation summation" up to infinite order. These corrected propagation equationsare better approximations than simple envelope equation, but it is difficult to see what is the true physical meaning of the required approximationsand whether or not the resulting equation is consistent, in the sense of taking into account all effects of the same order of smallness.

We present a derivation of an equation for light-pulse propagation that is based on full Maxwell equations and that is in principle exact. This equation reduces to the equationsof Brabec and Krausz, or to nonlinear Schrodinger equation after some additional approximations. Thus, it allows us to assess the role played by different levels of correction terms in the extreme nonlinear optics of ultrashort pulse propagation. The numerical implementation makes it possible to switch-on different corrections at will and thus "interpolate" between the simplest envelope equation, through to the corrected equations by Brabec and Krausz, to essentially Maxwell's equations. We report on some preliminary comparative numerical simulations.

A systematic study of the correction terms in the context of atmospheric pulse propagation and propagation in glasses are planned for the future with the aim of quantifying the conditions under which the application of such a sophisticated propagation equation is necessary.

J. R. O' Callaghan, J. Houlihan, V. Voignier, G. Huyet, J. G. McInerney

Physics Department, National University of Ireland, University College, Cork, Ireland.

B. Corbett and P. A. O' Brien

National Microelectronics Research Centre, National University of Ireland, Cork, Ireland

We present a simple broad area semiconductor laser using a current spreading layer to modify the transverse gain profile. The device exhibits excellent spatial coherence to total output powers of 2.5 W under pulsed operation. Devices have been focused down to a spot size of approximately 5 microns FWHM at 2.5 W with the beam profile and position remaining stable over the entire range of operation. Under CW operation, thermal effects reduce spatial coherence leading to a significantly increased spot size and loss of beam stability. This work demonstrates the advantages of modifying the transverse gain profile and how it can be used to produce high brightness devices required for single mode fiber coupling.

Eoin O'Reilly

Gain Characteristics of Ideal Dilute Nitride Quantum Well Lasers at the Cork Workshop.

Abstract

Recently dilute nitride GaNAs and GaInNAs compunds have been proposed as new semiconductor materials for the realisation of semiconductor quantum well (QW) lasers emitting in the 1.3 micron optical window. We present a theoretical analysis of the gain as a function of carrier density and radiative current density in ideal GaInNAs/GaAs QW structures, highlighting how the N-induced changes in band structure modify the gain characteristics compared to an "equivalent" N-free GaInAs/GaAs QW laser structure.

John D. Perreault

"Carrier-Envelope Phase Measurement of Ultrashort Pulses"
John D. Perreault

Reflection from a dielectric is investigated as a method for measuring the phase of the optical carrier relative to the envelope of an ultrashort pulse. Harmonic generation due to a second order susceptibility at the dielectic boundary is considered. Interference between the various harmonics of the reflected pulse in the Fourier domain is dependent on the carrier-envelope phase. The results of a numerical simulation of the non-linear driven wave equation are presented.

Christoph Schlichenmaier

Optically induced coherent intra-band dynamics in disordered semiconductors

C. Schlichenmaier, P. Thomas, T. Meier, I.Varga, and S.W. Koch

On the basis of a tight-binding model for a strongly disordered semiconductor a new coherent intra-band dynamics is found if the system is excited by two ultrashort particularly designed light pulses delayed by τ relatively to each other. In addition to the inter-band photon echo which shows up at exactly $t=2\tau$ relative to the first pulse, the system responds with two spontaneous intra-band current pulses preceding and following the appearance of the photon echo. The temporal splitting depends on the electron-hole mass ratio.

Marc Sciamanna

Polarisation self-modulation in a VCSEL subject to a 90° polarisation rotating external optical feedback

Abstract

Reported experiments on a VCSEL subject to a 90° polarisation rotating external optical feedback have shown that the intensities in the two linearly polarised modes of the VCSEL evolve periodically in antiphase with a period close to but slightly larger than two times the round-trip time in the external cavity. By combining continuation methods and direct integration of rate equations, we give an explanation for the appearance of this periodic state in the polarisation modes. Apart from the polarisation self-modulation regime, the complexity of the dynamics is presented and the influence of the external cavity length is shown. Our numerical results are in good agreement with the previous experimental findings while motivating new theoretical and experimental investigations

Cork Workshop Poster Presentation: Markus Sondermann

Two-mode emission and competition of orthogonal polarised modes at lasing threshold in a VCSEL

M.Sondermann, T. Ackemann
Institut für Angewandte Physik, Universität Münster, Correnstraße 2-4, Münster, Germany

We investigate the emission of two orthogonal polarised modes at lasing threshold in a vertical-cavity surface-emitting laser (VCSEL). A simultaneous increase of the time averaged power in the corresponding polarisation directions is observed at threshold. If the current is increased sufficiently high above threshold, one mode dominates and the orthogonal polarised mode is depleted continuously. An investigation of the threshold behaviour with high time resolution reveals fast polarisation dynamics and anticorrelations.

Antiphase dynamics in chaotic multimode semiconductor lasers

A. Uchida, Y. Liu, I. Fischer, P. Davis, and T. Aida

ATR Adaptive Communications Research Laboratory
2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0288 Japan

Abstract

We report experimental observation of anti-phase mode dynamics in the high-frequency chaotic state of a multi-mode semiconductor laser with optical feedback and provide a detailed investigation of its frequency dependence. Comparison of the power spectral density for total intensity with the incoherent sum of power spectral densities for individual mode intensities shows that the oscillations around the relaxation oscillation frequency are in-phase in all the modes, while the oscillations at lower frequencies exhibit partial anti-phase behavior. We demonstrate that synchronized phase dynamics with similar frequency dependence

can be induced in a second laser by unidirectional optical injecti on.

Cork Workshop Poster Presentation: Craig Walker

Title: Sputtered Silica Enhanced Quantum Well Intermixing of GaAs/AlGaAs Lasers.

Abstract: Monolithic integration of components such as lasers, passive waveguides and modulators is essential for opto-electronics to achieve its full potential. A key technological requirement for integration is the ability to control the band-gap energy of QW material over the entire wafer. Quantum Well Intermixing (QWI) is a suitable technology for this integration. The sputtered silica QWI technique is outlined, followed by two different examples of lasers fabricated using this advanced technology.

Cork Workshop Poster Presentation: Mirvais Yousefi

Title : On the Control of Filtered Optical Feedback in Semiconductor Lasers

Abstract : Our analysis of the rate equations describing a semiconductor laser subject to filtered external optical feedback show that the dynamics can be controlled through the filter parameters : The filter resonance frequency and its bandwidth. To demonstrate this we calculate a transition in and out of chaos induced by varying the detuning between the solitary laser frequency and the filter center.